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Potential of In-Duct Hydropower Generation in Makueni County, Kenya

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ABSTRACT
Literature shows that only 56% of Kenyan households had access to electricity, with rural areas having the lowest access rate at 31%. The high cost of extending the power grid to remote areas and power losses on distribution are significant challenges facing rural electrification. In addressing power accessibility problems especially in the rural areas, there is a need for tapping hydropower generation through invention and implementation of in-duct turbines to maximize the utilization of already existing pressurised water ducts that supply water in various parts of Kenya for hydropower generation. This work focuses on identifying and mapping possible Micro Hydropower (MHP) sites for hydropower generation in Makueni County located in Eastern Kenya. The County is supplied by four gravity fed water ducts with slope lengths ranging from 40m to 800m. The study focussed mainly on duct sections with heads ranging from 14m to 183m located in Kweleli and Manooni water supply schemes in Nzaui Sub-County, and Ikokani and Mulima water supply schemes in Mbooni West Sub-County with pipe diameters ranging from 50mm to 200mm which offer a significant potential for construction of pico/micro hydropower generation systems.
Potential micro hydropower sites were identified, evaluated, and mapped using the Open Data Kit (ODK) approach and GPS mapping. The heads/heights of possible locations along the gravity ducts were determined by recording the heights above sea level (asl) of the pipeline slope start and slope end along the pipelines using GPS and collecting hydraulic head data along the county's the four selected water supply ducts. The maps were generated using a quantum geographical information system (QGIS) where the prospective MHP locations varied in several ways, including particular power estimates ranging from 0.59 to 23.63 kilowatts. According to the analysis, there are 33 viable sites along the four water projects in which thirteen possible MHP locations were sited along Manooni, nine along Mulima, eight along Ikokani, and three along the Kweleli water supply pipelines. Applying an efficiency value of 0.7, out of the 33 identified potential MHP sites, six (6) had power ranges of 15 to 25KW, two (2) had power ranges of 10 to 15KW, five (5) had power ranges of 5 to 10KW, nineteen (19) had power ranges of 1 to 5KW, while one (1) site had a power range of 1 to 5KW.
Based on these findings, it is concluded that excess energy (pressure energy) from the flowing water inside ducts can be extracted to meet electric power demand for rural communities in Makueni County, Kenya. It is clear from this research findings, that significant power/energy can be harvested from the ducts in different operating conditions and applications and provide a real promising alternative technology for power generation especially in rural areas of Kenya and other countries.

***KeyWords* – Break pressure tank (BPT), Duct, Hydropower, Modeling, Renewable Energy, Small Hydropower Schemes, GPS and quantum geographical information system (QGIS)**

1.0 INTRODUCTION

Hydropower is a mature and cost-competitive renewable energy technology that plays a strategic critical position in the electricity mix of the twenty-first century, accounting for more than 16% of global electricity output and around 85% of global renewable electricity. Literature review shows that hydropower capacity has been increasing steadily in the world and over 160 nations depend on hydropower for socio-economic development. Hydroelectricity offers various benefits over other electrical power sources, including high dependability, established technology, great efficiency (about 90% efficiency), very cheap operating and maintenance costs, flexibility, and substantial storage capacity [1]. Furthermore, given the instability of other renewable energy supplies such as wind and solar, hydropower systems can aid in moderating oscillations between demand and supply. This is possible because to the wide range of hydropower plant sizes. Kenya's electricity generation is liberalized, with hydropower dominating the energy mix [2].
In this study, the potential of hydropower electric power generation from water flowing through pipes was investigated, particularly vertical pipelines, which have a lot of kinetic and pressure energies. Inside the duct, the flow rate is usually constant, and the end-user requirement is simply flow rate rather than pressure. As a result, a portion of the pressure energy

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can be collected and transformed into electrical energy [2]. Several technical methods have been proposed to replace pressure-reducing valves with energy-producing devices, allowing for effective power conversion from reliable water network pressure regulation.

Considering the implementation of the feed-in tariff (FIT) policy in 2008, small-scale candidate sites are emerging and serve well for the delivery of power to communities, small companies, or farms [3]. Aside from the few big and medium hydropower schemes functioning in Kenya, others include (i) small (10-1 MW), (ii) Mini (1MW - 100 kW), (iii) micro (100kW - 5 kW), and pico (5 kW) hydropower [4].

1.1 Micro Hydropower Potential

A micro hydropower plant (MHP) is a renewable energy source that is created by falling water through an open or closed waterway that drives a turbine coupled to an electric generator. MHP is regarded to be an appropriate renewable energy source for homes, ranches, and remote villages. MHP technology is the most mature of the renewable energy power plant technologies, with better efficiency (70-90%) than wind, wave, and solar power plants. MHP electricity can be utilized for a variety of purposes. MHP can continually generate electricity and be connected directly to the load without the need for an energy storage system with the right system planning and design. Applying a variable speed mechanism can increase MHP efficiency and stability of power networks [5]

1.2 Study Area

The study area is Makueni County, which borders Kajiado County to the west, Taita Taveta County to the south, Kitui County to the east, and Machakos County to the north. It is located in the dry and semi-arid zones of Kenya's Eastern region, between Latitude 1^0 35' and 3^0 00' South and Longitude 37^0 10' and 38^0 30' East. Rural areas and the majority of Makueni County are already marked by a shortage of power [6].

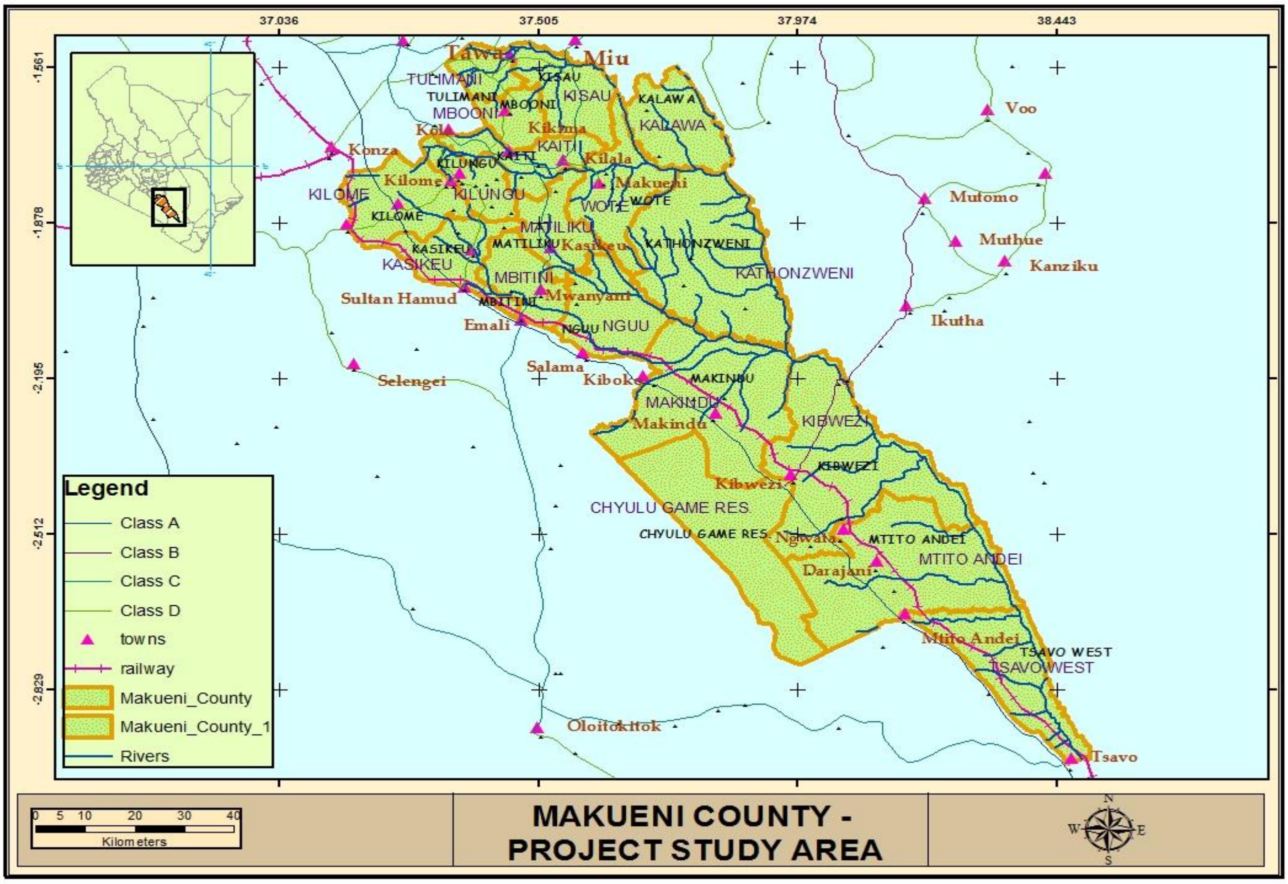

Figure 1: Study area Map (courtesy of Makueni County)

According to Makueni County Government, the County is endowed with community water supply systems gravitating to settlement areas from the Volcanic Chyulu, Mbooni, Nzaui, and Kilungu hills, hence if the potential hydro energy is developed, would aid in reducing energy deficit in rural areas by reaping green energy from small diameter (100mm to 200mm) community gravity water ducts [6]. This would also help with water pressure management by reducing pipeline ruptures and the associated repair expenses as well as disruptions in water supply to customers [7]. Furthermore, the

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development of such MHPs in the local communities would increase awareness of the benefits associated with the use of renewable energy technologies (RETs) in Makueni County's power matrix, particularly through the harvesting of hydropower from small gravity water ducts.
A reconnaissance assessment and analysis of the Makueni Water pipeline profiles clearly shows that possible places along the gravity pipelines exist, where Micro hydropower (MHP) schemes could be created to generate green hydro energy to supplement the County's energy sources. The diameters of water ducts in rural areas range in from fifty millimetres (50mm) to two hundred and fifty millimetres (250mm). Water pipeline profiles in Makueni County design Office show the existence of such pipeline trunks extending down from various hills to low places.

2.0 RESEARCH METHODOLOGY

Focused on identification and mapping of prospective MHP sites along gravity community ducts that transport water in rural regions, Makueni County was selected as a study area because it has gravity water schemes hence high potential for in-duct hydropower generation. The research was carried out in three stages thus data collection, data processing, and data analysis. During the first phase, data collection questionnaire was designed to capture the site name, date of data collection and the GPS data for all the potential sites for installation of MHP systems. Other data collected include key features of water pipeline including intakes, pipeline heads, streams, rivers, storage tanks, break pressure tanks (BPTs), washouts and valves. The identification and mapping of the potential MHP sites was done though application of ODK as shown in Figure 1

2.1 Data collection in 1st stage

During the 1st stage, data collection included use of topographic maps, remote sensing data, and field measurement via

The flow of water (Q) was calculated by considering the amount of water collected in a container divided by time (t) taken to fill the container [8]. The potential power generated from the micro hydro power scheme was calculated from the information gathered through the site survey [9]. The actual power generated from the given source of water is given by;

$$P = \rho . g . H . Q . \eta \quad \text{.......} \quad 2.1$$

where P = electrical or mechanical power produced in Watts (W), ρ = density of water (kg/m^3), g = acceleration due to gravity (m/s^2), H = elevation head of water (m), Q = flow rate of water (m^3/s), η = overall efficiency of MHPS [10]
The elevation heads of possible locations along the gravity ducts were determined by measuring/picking the point elevation heights above sea level of each pipeline slope start and slope end using GPS and collecting hydraulic head data along the county's selected water supply ducts. The maps were created using a quantum geographical information system (QGIS).
The researcher used the ODK) process to collect data and GPS to map major pipeline locations to identify and map possible MHP sites. ODK is an open software which is expandable for gathering, managing, and utilizing data. ODK is an open-source collection of tools developed to build information services for developing regions [11]. A data collection questionnaire was first designed in Microsoft word format for all the key data which was to be collected. Such data were; the site name, date of collection, main feature around i.e. storage tanks, BPTs, and the GPS points for all the potential sites and key features including intakes, pipeline slope starts, slope ends, streams, rivers, storage tanks, BPTs, washouts and valves among others. Map production was done in a quantum geographical information system (QGIS) environment. The data was analyzed and overlaid with administrative boundaries to produce the maps for the water pipelines and potential micro hydropower sites. The ODK process was used to carry out data collection and mapping of key pipeline points as diagrammatically summarised in figure 2.
The gravity water schemes subjected to the study were: Kweleli, and Manooni, in Nzaui Sub-County, Ikokani and Mulima in Mbooni West Sub-County and had pipe diameters ranging from 50mm to 200mm hence had high potential for development of micro hydropower Schemes. An assessment was undertaken using ODK fed data collection questionnaire while analysis was done using excel sheets. Using mobile phones, geographical information system (GIS), and global positioning system (GPS) mappers, coordinates of all the intakes, pipelines sections, water storage tanks, break pressure tanks, slopes elevation heights, and possible MHP Sites were taken. The assessment was undertaken along the water ducts especially where the ducts were in steady slopes and would provide adequate water heads for hydro power production. All the sites along the selected water projects of Manooni, Mulima, Ikokani and Kweleli were mapped as indicated in figures 3, 5, 7 and 9 respectively.

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2.2 ODK Process Diagrammatic Summary

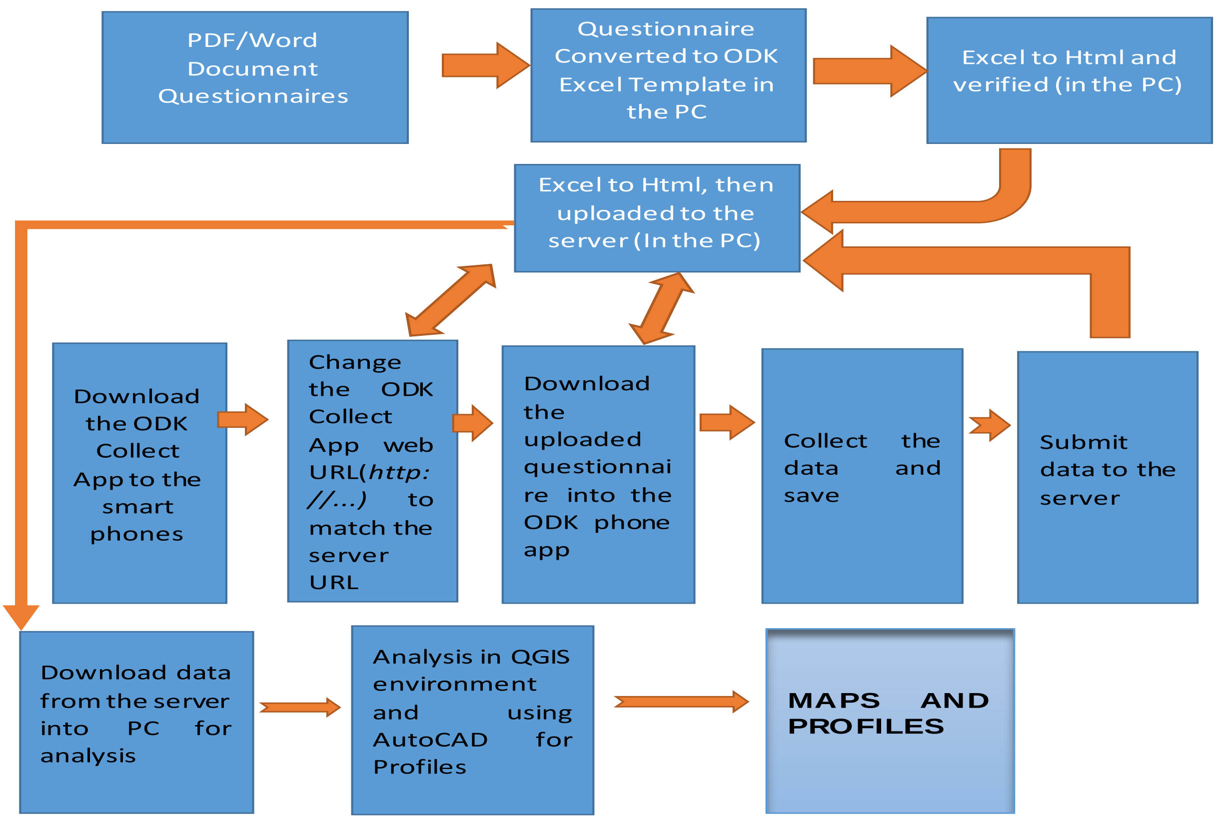

Figure 2: Diagrammatic Representation of Sites Mapping Process

3.0 RESULTS AND DISCUSSIONS

The research results show that the gravity water schemes had ducts with diameters ranging from 50mm to 200mm, slopes lengths ranging from 40m to 800m while the slopes had sections elevation heads varying from 14m to 183m. Further analysis of the section gradients pinpointed to 33 potential micro hydropower production sites with production estimates ranging from 0.59 to 23.63 kilowatts.

As shown in figure 3, out of the 33 identified potential MHP sites, 13 sites were along Manooni, 9 sites along Mulima, 8 sites along Ikokani and 3 sites along Kweleli water scheme ducts. While applying an efficiency coefficient of 0.7, Six (6) potential MHP sites had a power range of 15 to <25KW, Two (2) potential MHP sites had power range from 10 to <15KW, Five (5) potential MHP with a power range from 5 to <10KW, Nineteen (19) potential sites MHP had a power range of 1 to <5KW while only one (1) potential MHP site power production was in the range of 0 to <1KW.

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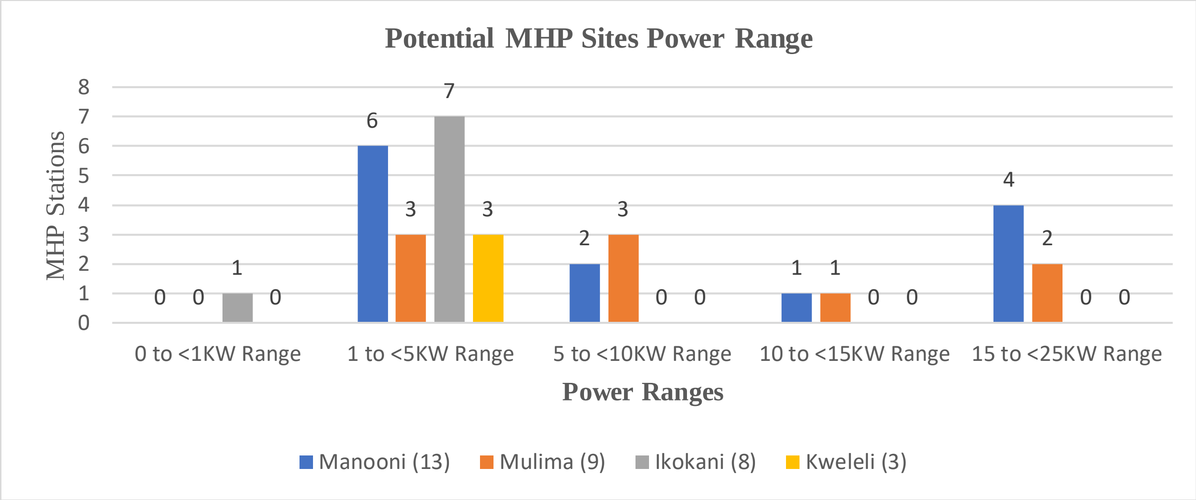

Figure 3: Potential MPH Sites Power Ranges

3.1 Manooni Water Project

The source of water for Manooni water project is rainwater surface runoff harvested through Manooni dam after which water supply is mainly, supplied to consumers using gravity systems. The dam reservoir has a capacity of approximately 0.25 million cubic meters and is in Kilungu (Manooni- Matiliku) hills hence water flows from the hills to distribution lines with sufficient hydraulic heads for possible development of micro hydroelectric power stations. The flow of water from the intake was found to be 10 litres per Second and the project consisted of the main line of 200mm diameter from the dam to Kitulani ground Masonry tank near kwa Mutula market through Utuneni to Mulala at Kathuma Market and reduces to 75mm diameter at kwa musomi storage tank. The GIS points of all the potential micro hydropower stations are presented in a map as shown in figure 4.

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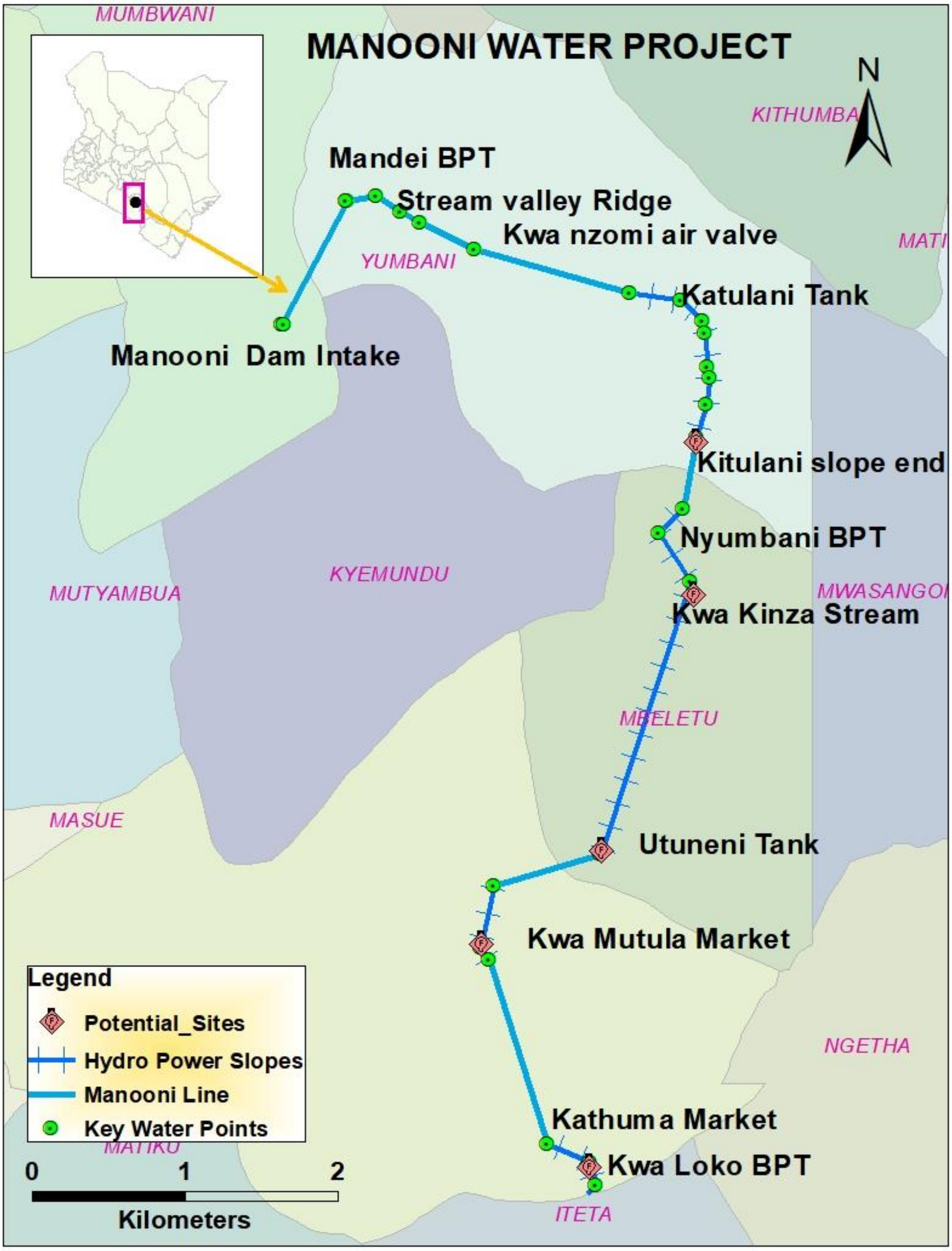

Figure 4: Manooni Water Project Map

The potential hydropower for various identified Potential sites along Manooni water project pipeline ranged between 2,106W for a head of 22m and 23,632W for a head of 129m. The potential sites and hydropower production levels are presented in figure 5.

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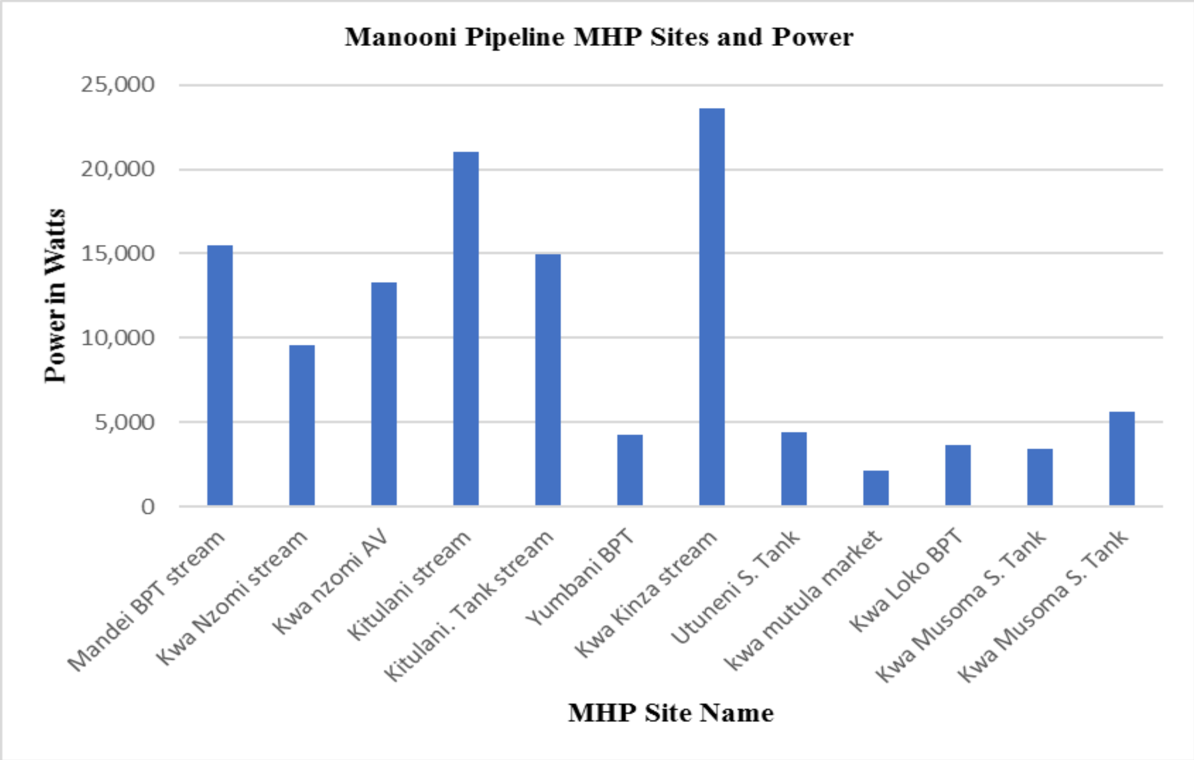

Figure 5: Manooni MHP Sites and Potential Power

3.2 Mulima Water Project

This project has its intake at Nzeveni in Mbooni hills slopes and its managed by Mbooni Water and Sanitation Company. The source of water is permanent water springs in the forest upstream which feeds Mulima Earth Dam besides harvesting surface runoff during rainfall. The dam has a capacity of 0.1million litres active storage capacity. Water flows by gravity from dam intake chamber to mavindu storage tank. The flow from the dam is 30 litres per second. The project starts with 225 mm diameter pipe and reduces to 75mm in the lower sides towards Tawa market. The GIS points of all the potential micro hydropower stations along the pipeline are presented in a map as shown in figure 6.

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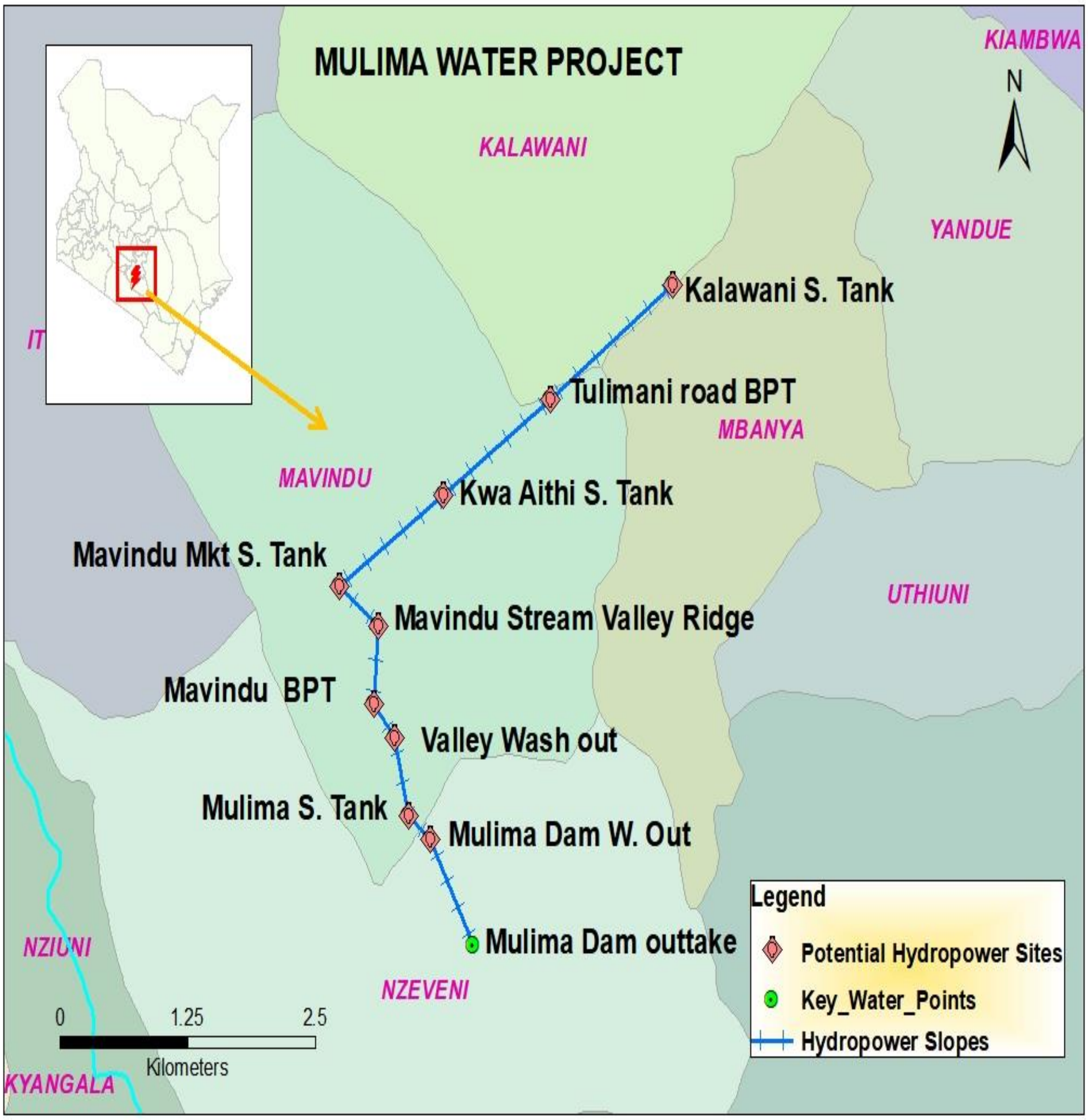

Figure 6: Mulima Water Project Map

The potential hydropower for various identified sites along Mulima water project pipeline ranged between 2500W for a head of 55m and 19,142W for a head of 85m. The potential sites and hydropower production levels are presented in figure

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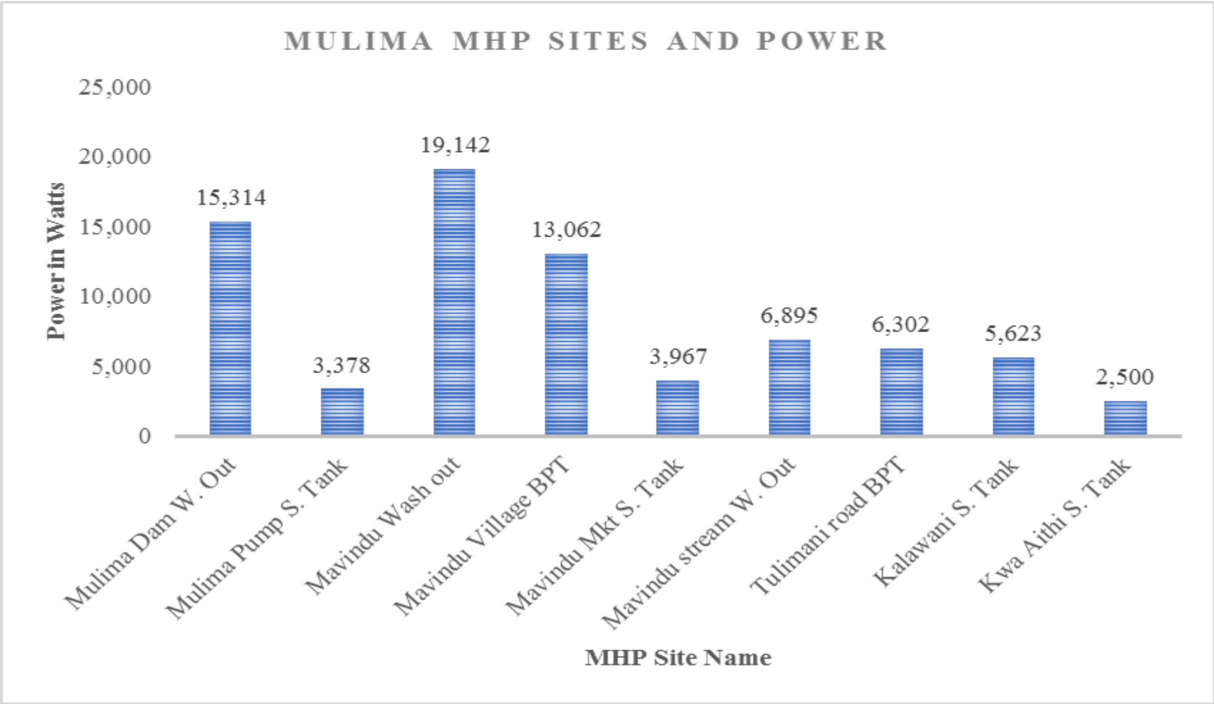

Figure 7: Mulima MHP Sites and Potential Power

3.3 Ikokani Water Project

Ikokani water project is in Mbooni hills and its intake is built across Ikokani River near Nzaini Coffee Factory. The river is recharged upstream at Mutituni and Wathi area by permanent springs which help in stabilizing water flow. The river flow is 10 litres per second while the flow in the pipe is 2 litres per second. The GIS points of all the potential hydropower stations along the pipeline are presented in a map as shown in figure 8.

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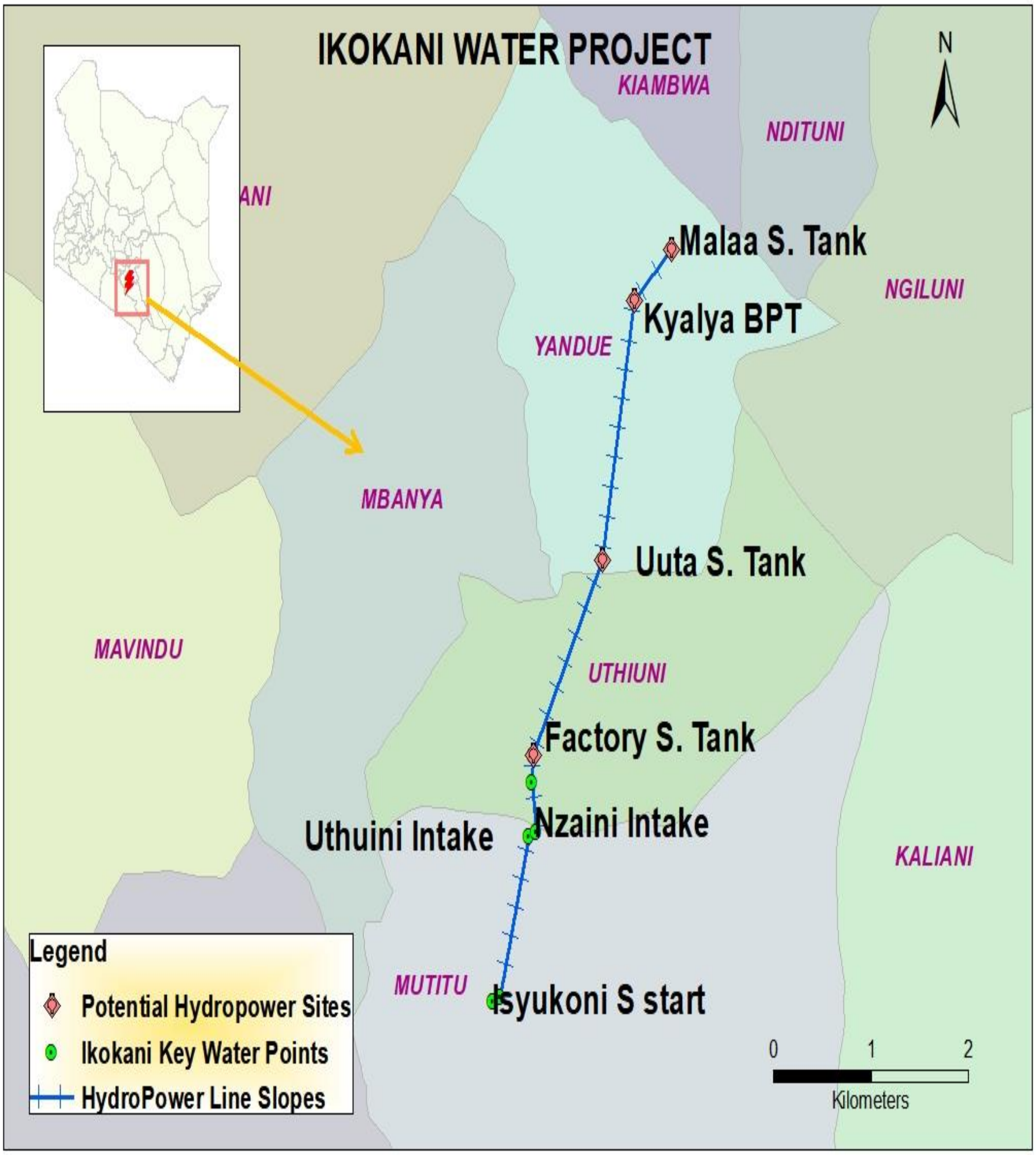

Figure 8: Ikokani Water Project Map

The potential hydropower for various identified sites along Ikokani water project pipeline ranged between 585W for a head of 17m and 4580W for a head of 133m. The potential sites and hydropower production levels are presented in figure 9.

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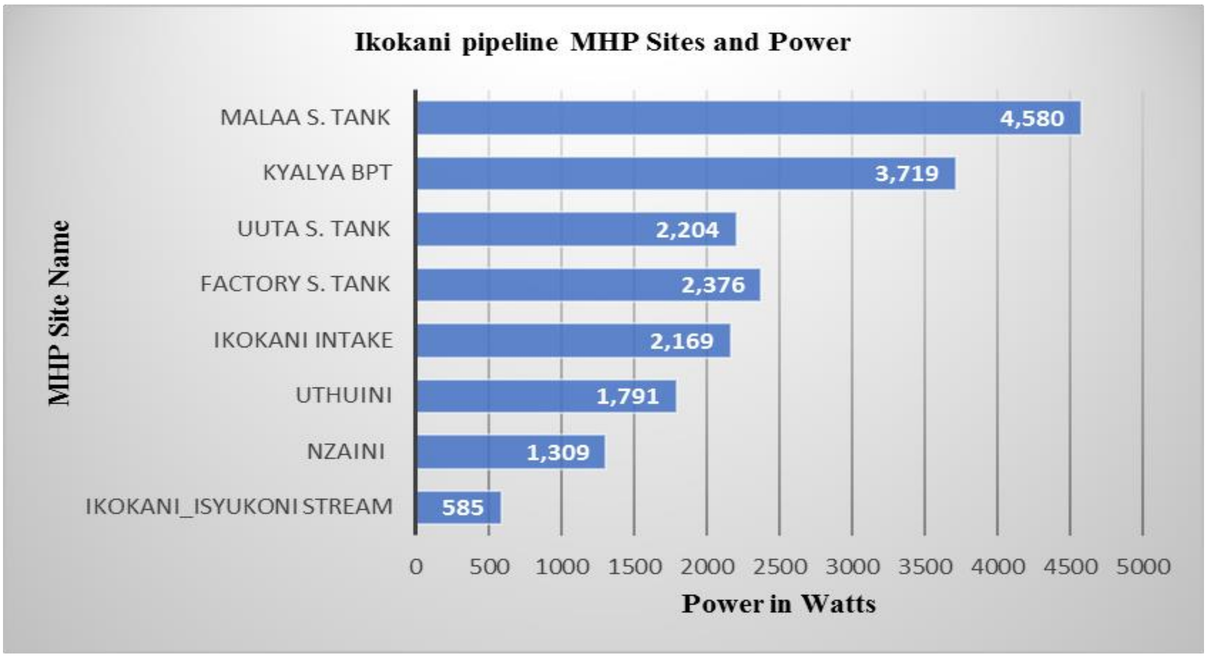

Figure 9: Ikokani MHP Sites and Potential Power

3.4 Kweleli Water Project

The Kweleli water project intake is in Nzaui hills and the water source is a spring deep inside the Nzaui hills forest where water is collected from an intake box using a 100mm diameter pipe which runs for 200m to Ngangani storage Tank. The Ngangani tank to Yiuma market line is 75mm diameter. The flow from the spring is 3 litres per second and only 1.8 litres per second flows along the pipeline with the rest left for environmental flow. The GIS points of all the potential micro hydropower stations along the pipeline are presented in a map as shown in figure 10.

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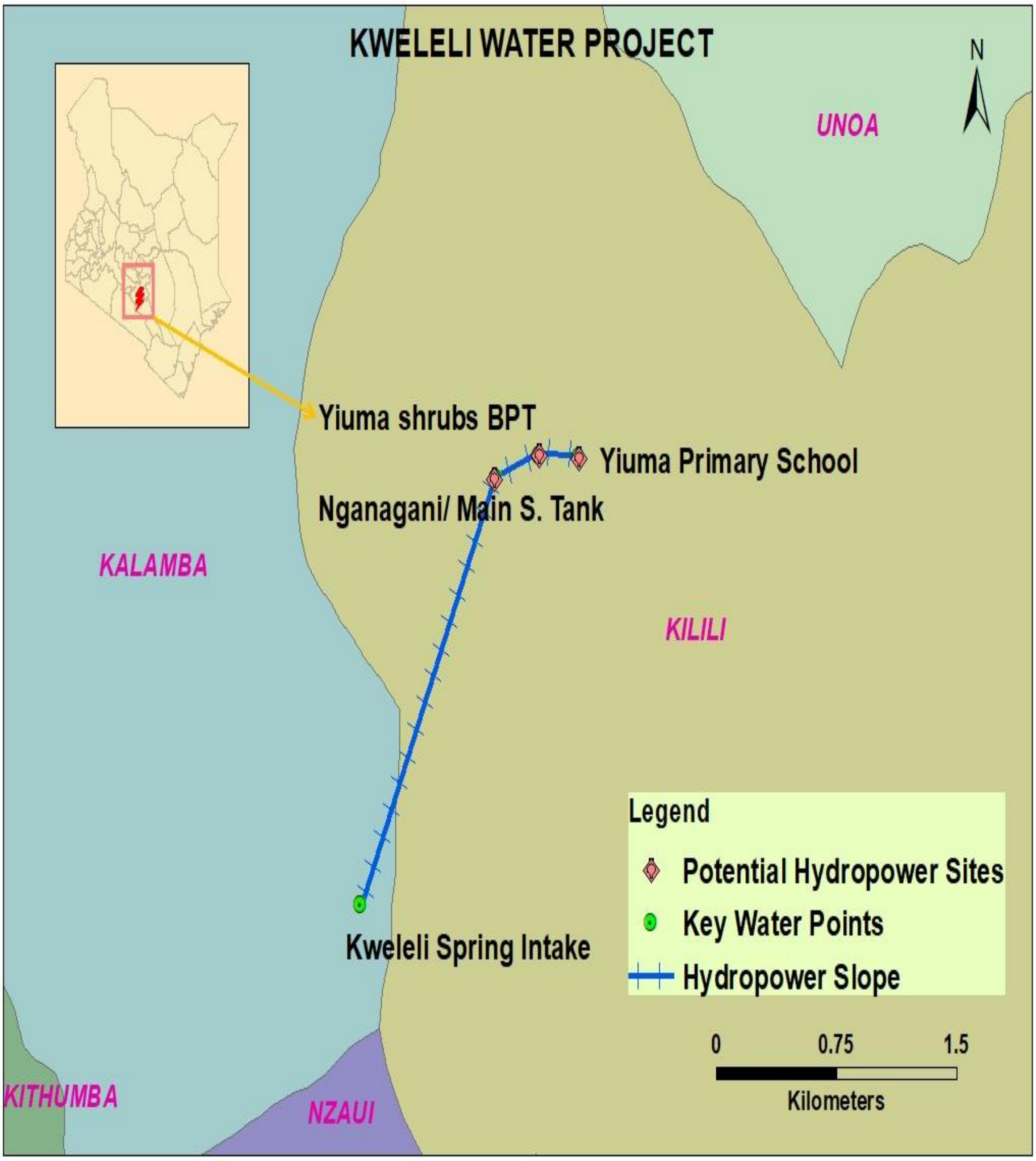

Figure 10: Kweleli Water Project Map

The potential hydropower for various identified sites along Kweleli water project pipeline ranged between 2445W for a water head of 71m and 3,891W for a water head of 113m. The potential sites and hydropower production levels are presented in figure 11.

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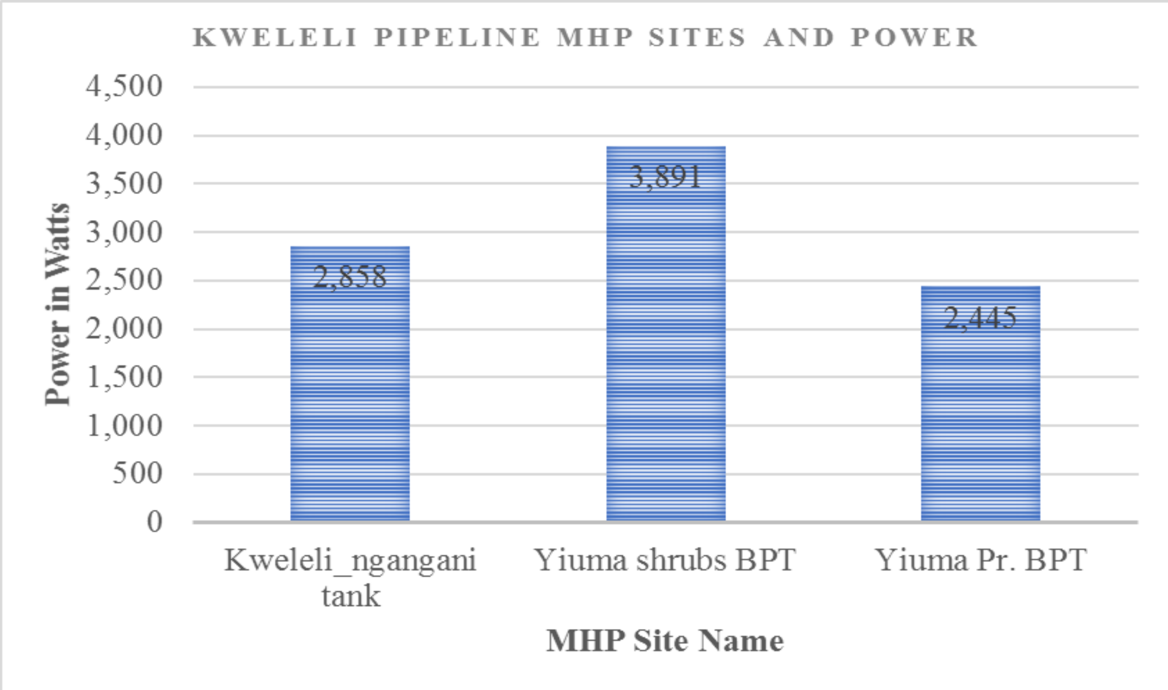

Figure 11: Kweleli MHP Sites and Potential Power

4.0 CONCLUSIONS AND RECOMMENDATIONS

On the basis of these findings, it can be concluded that in-duct power generation technology in which small water turbines are installed in water ducts are among the most promising energy harvesting systems to meet electric power demand for rural communities.

Development of micro/pico hydropower, will avail energy to communities and institutions in the rural areas for income generating activities hence opening their minds to business development.

Development of MHP sites will break pressure along the pipelines by acting as break pressure tanks (BPTs) hence significantly reduce cost of pipeline repairs caused by bursts as a result of high pressures and water hammer

Production of hydropower from ducts will provide a paradigm shift to the rural communities' source of energy and its use hence reduce use of firewood for cooking which is at 89% in Makueni County and reduce deforestation.

The urban/rural water and sanitation companies (WASCOs) managing water service provision ensure proper and timely maintenance of the water schemes to ensure continuous flow of water for energy production.

More studies are recommended on improved technologies of harnessing hydropower from existing hills in Kenya with focus to production of micro/pico hydropower from ducts less the 50mm diameter which are very common in rural areas.

5.0 REFERENCES

1. Gokhale, P., Date, A., Akbarzadeh, A., Bismantolo, P., Suryono, A. F., Mainil, A. K., & Nuramal, A. (2017). A review on micro hydropower in Indonesia. Energy Procedia, 110, 316-321.
2. Miller, S. T. (2016). Geothermal Electricity Compared To Electricity From Other Sources In Kenya (Master's thesis). http://repository.pauwes-cop.net/handle/1/146
3. Ndiritu, S. W., & Engola, M. K. (2020). The effectiveness of feed-in-tariff policy in promoting power generation from renewable energy in Kenya. Renewable Energy, 161, 593-605.
4. Shrestha, J. N., Techato, K. A., Khongnakorn, W., Gyewali, S., & Dangal, M. R. (2022). hydropower-Renewable Energy Solution for Sustainable development: A Review of hydropower development in nepal. Water and Energy International, 65(1), 44-52.
5. Bilgili, M., Bilirgen, H., Ozbek, A., Ekinci, F., & Demirdelen, T. (2018). The role of hydropower installations for sustainable energy development in Turkey and the world. Renewable Energy, 126, 755-764.
6. Makueni County Government, (2018). Makueni County Integrated Development Plan (CIDP): Makueni County Government.
7. Berardi, L., & Giustolisi, O. (2021). Calibration of design models for leakage management of water distribution networks. Water Resources Management, 35(8), 2537-2551.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 08, August - 2023

8. GoK, (2005). Design manual for Water Supply in Kenya: Ministry of Water and Irrigation.

9. Tesema, G., & Workesa, M. (2016). Development and Evaluation of Water Powered Machine for Rural Electrification and Flour Milling in Oromia, Ethiopia. Development, 3(3).

10. Gyawali, N. P. (2017). Microhydro-based mini grid for sustainable development of rural communities: A case study of nepal. Sustainable Power Systems: Modelling, Simulation and Analysis, 151-174.

11. Brunette, W., Sudar, S., Sundt, M., Larson, C., Beorse, J., & Anderson, R. (2017, June). Open Data Kit 2.0: A services-based application framework for disconnected data management. In proceedings of the 15th annual international conference on mobile systems, applications, and services (pp. 440-452).